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WICKSTEED
ON THE
CORNISH
ENGINE

AN EXPERIMENTAL INQUIRY

CONCERNING

THE RELATIVE POWER OF, AND USEFUL EFFECT PRODUCED BY,

THE

CORNISH AND BOULTON AND WATT
PUMPING ENGINES,

AND

CYLINDRICAL AND WAGGON-HEAD BOILERS.

BY

THOMAS WICKSTEED,

ENGINEER TO THE EAST LONDON WATER-WORKS, MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS, AND
HONORARY MEMBER OF THE ROYAL CORNWALL POLYTECHNIC SOCIETY.

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TO ARTHUR AIKIN, ESQ., F.L.S., F.G.S.,

&c., &c., &c.

My dear Sir,

However imperfect may be the mode of treating the subject of the following pages, it is nevertheless one of great interest and importance; and as my aim has been to obtain and record facts connected with a leading branch of Enginery, you, I am persuaded, will not undervalue the intention. To whom can I so appropriately dedicate this production as to yourself, who first led me to the study of Enginery, who first taught me to seek for facts on which to found opinions, and by whose kind assistance I was enabled to enter my profession?

I feel, therefore, assured that I may claim your indulgence for all the defects in this composition, which I sincerely wish was more worthy of your notice, and a better tribute of acknowledgment of that unvarying friendship with which I have been so long honoured.

I am, my dear Sir,
Your obliged and faithful Servant,
THOMAS WICKSTEED.

Sept. 22, 1841.

PREFACE.

Those who take up the following Paper in the expectation of meeting with a theory of the Cornish Engine will be disappointed, as it is little more than a plain narrative of the result of experiments made with a view to establish the *commercial* value of two classes of Pumping Engines.

It is also intended to do justice to those who have had any share in introducing the Cornish Engine into London, by a relation of the circumstances connected therewith.

This Paper was originally intended for the Institution of Civil Engineers, but as the details were not completed in time to allow of its being read before the Institution, (although its reception was announced at the last meeting,) the Council, to prevent the delay that would have occurred if it were retained until the next session, has kindly permitted the Author to withdraw it, for the purpose of publication in the present form.

The subject has of late years become one of great interest to the public; and although the Author believes he may take credit to himself for having, in opposition to the opinions of several eminent Engineers, persevered in supporting his favourable views respecting the Engine, until he obtained the desired object, namely, of proving their correctness, by the erection of one in London, he cannot, without injustice to Mr. Walker, the President of the Institution of Civil Engineers, omit to mention the part which that Gentleman took in promoting the discussions that have taken place on this question.

The Author's original object was solely to obtain an Engine of the best class to raise water for the East London Water-Works, with which he is professionally connected. Mr. Walker, however, hearing that he had made a survey of Cornish Engines, strongly urged that an account of that survey should be sent to the Institution. A Paper was accordingly prepared and read before the Institution, and this was the origin of the discussions that have since taken place.

Although Mr. Walker had full reliance on the Author's statements, from a knowledge of his character, others imagined that he might have been misled by the representations of interested parties; and, in consequence of these doubts, Mr. Walker advised and urged him to ascertain, when an opportunity offered, the exact weight of coals consumed in raising a given quantity of water, and especially to *weigh* the water raised at each stroke of the engine; as many, unacquainted with the subject, conceived that the Cornish Engineers published fallacious accounts of the quantity of water raised.

These experiments were made, and the result recorded in a letter addressed to Mr. Walker, which was read before the Institution, and so far completely verified the calculations of the Cornish Engineers.

In the course of the discussions alluded to, the Author soon found that the information acquired by those who professed decisive opinions upon the subject was not sufficient, as he thought, to enable them to arrive at just conclusions, as to the cause of the superiority of the Cornish Engine over the ordinary low pressure non-expansive Engine. He therefore pledged himself to make experiments, and thenceforth abstained from expressing any positive opinion on the matter, and from taking any share in the subsequent discussions.

In the first Paper referred to, the claims of the great James Watt, (whose surpassing genius has left little to be done by his successors,) to the first introduction of the method of working steam expansively, and to the clothing of the boilers, cylinders, and steam pipes, with a non-conducting substance, are set forth; and in this Paper it is hoped that, although it may be difficult to avoid a prejudice in favour of what that extraordinary man has done, no praise due to those who have carried out the system introduced by him to its present unprecedented extent has been withheld.

The Cornish Engineers have carried out the system of working steam expansively much farther than any other Engineers, and great credit is due to them for the skill they have displayed, the constant attention they have devoted to the improvement of the engine and pit-work, the perfection of their mode of clothing, and the great economy they have consequently introduced in the working of their mines. To none, I believe, is greater credit due than to Mr. William West, the Engineer of the Fowey Consols.

Although economy of fuel is a subject of the greatest moment, nevertheless there are other considerations of importance which must not be lost sight of; and, while credit is given to the improvers of one class of Engines, the exertions of others who have rendered the Steam Engine more applicable to the infinite variety of Manufactures of this Country, and to the purposes of Navigation and Locomotion, should not be passed unnoticed.

Nor has economy of fuel been forgotten by these improvers; and although this point may, and certainly will be carried to a greater extent than it has yet been, nevertheless those who know the difference between an Engine for giving motion to machinery, and one for simply raising water, must be well aware that the same useful effect cannot be produced by the former as by the latter, with the same consumption of coals.

With respect to the calculations introduced into this Paper, it is to be observed that the mode in which they have been worked is given, as well as the results recorded. If, therefore, the calculations are objected to, an opportunity is afforded of adopting a different method. The facts will remain the same, and it is hoped they cannot fail to be useful.

INTRODUCTION.

Having been occupied at intervals, during the last three years, in making experiments upon the Cornish and Boulton and Watt Engines and Boilers erected at the East London Water-Works, Old Ford, I propose in the following Paper to record the results of my experience. To account for the delay in its publication I have to observe, that the results of the first experiments proving very discordant, I considered it necessary to repeat them, and continue them for a much longer period than I had in the first instance contemplated, in order to arrive at satisfactory practical conclusions.

My object in making these experiments has been to ascertain as accurately as possible the comparative value of the two engines as machines for raising water, to enable me to determine *practically* which is the best in a *commercial* point of view; and therefore, although I may be led to remark upon the *practical* results stated to have been arrived at by others, I shall abstain, as much as possible, either from noticing *theories* broached by others, or offering any myself, leaving every one to form his own opinions upon the facts stated.

As the Cornish Engine on which I have made experiments is the first, I believe, that has been erected and worked in London, the following short statement of the circumstances connected with its introduction may, I think, with propriety be made here.

In the spring of 1835 the Directors of the East London Water-Works Company contemplated making very considerable alterations in one of their engines at Old Ford, and it was then suggested by Mr. Grout, one of the Directors, that instead of altering the engine in question, it should be taken down, and a Cornish Engine erected in its place; and he stated that the saving in fuel that would be effected by adopting his suggestion, would amply repay the Company for the increased outlay consequent upon the erection of a new engine.

I am told that but little reliance was placed upon the accuracy of this information: my opinion was, however, called for, when I stated, that although I had never seen a Cornish Engine at work, I understood the principle of its action, which my friend, Mr. John Taylor, had explained to me as far back as 1826; and I was also aware of the favourable views entertained by the late Mr. Watt, of the advantages to be derived from using steam expansively, and had therefore no doubt that the effect produced by the Cornish expansive engines was much greater than that produced by the non-expansive engines.

In August, 1835, I was instructed to visit several of the mines in Cornwall, for the purpose of obtaining information respecting the engines in use there; and although my report was highly in favour of them, the opinions expressed in favour of the *old* system, and against the *new*, advocated by me, were nevertheless so numerous, and of such high authority, that it was not until two years afterwards, in 1837, (upon Mr. Grout's information that a good second-hand engine was to be disposed of at a comparatively low price,) that I was instructed to proceed to Cornwall for the purpose of purchasing it.

I have made the foregoing statement, because I consider it due to Mr. Grout for the perseverance which he displayed. I would not, however, wish it to be understood that I consider his colleagues could, in opposition to the opinions of many professional men, have consented to embark the property of the proprietors in what *then* appeared to many a *mere* speculation, without great caution and strong presumptive evidence, amounting almost to proof, that the opinions of the few in favour of the project were correct.

The engine purchased by the Company, which had been worked about 12 months at the East Cornwall Mines, near Callington, had been designed by Mr. William West, and was a counterpart of one designed and erected by him at the Fowey Consols Mines, which performed the greatest duty ever recorded. In August, 1837, contracts were entered into with Messrs. Harvey and Co., of the Hayle Foundry, and Mr. William West, to take the engine down and thoroughly repair it, to make a new boiler, and alter the old ones, to make the pump-work, and the stand-pipe; and to convey the whole of the work to, and erect it on, the Company's premises at Old Ford; which work, when completed, cost about £7600.

The principle of working a plunger-pole loaded, discharging the water into a stand-pipe, and dispensing with the air-vessel, was suggested by me with a view of following out the Cornish plan as completely as possible. Messrs. Harvey and West approved the suggestion, and designed the machinery.

Messrs. Harvey and Co. were bound, under a heavy penalty, to effect an average duty during 12 months' regular work of the engine, equal to 90 millions of ℔., raised 1 foot high, by the consumption of 94 ℔. of good Welsh coals, which was accomplished.

In December, 1838, the engine was first started, and worked very satisfactorily, a great saving in fuel being immediately effected: the pump valves, however, being of extraordinary dimensions, caused so great a blow upon closing, that the concussion shook the whole of the engine-house; several valves variously modified, but similar in principle to those in general use in the Cornish Mines, were made at a great expense to the contractors, but without remedying the defect: at last, however, Messrs. Nicholas Harvey and William West invented the self-acting double beat valves, which were made and set to work in July, 1839. The blow caused by the shutting of these valves is so much less than with the former ones, that there is no necessity for the admission of any air under them, there is no loss of water through them, and consequently a very great saving is effected by the use of them.

I propose dividing this Paper into two parts; the first relating to the boilers and fuel, the second to the engines.

PART I.—ON BOILERS.

I now proceed to give an account of the experiments made upon cylindrical and waggon-head boilers, with a view to ascertain their comparative merits; and, to show that the results I have arrived at are not founded upon *short* trials of a few hours' duration, (which, according to my experience, are useless for practical purposes,) it may be here stated that the time occupied in the trials upon the cylindrical boilers was above 3400 hours, the coals consumed above 900,000 ℔., and the water evaporated nearly 7¾ millions of ℔.—Upon the waggon-head boiler the time occupied was 1291 hours, the coals consumed nearly 600,000 ℔., and the water evaporated above 4½ millions of ℔.

When I first undertook these experiments, I imagined that several trials of short duration would answer the purpose, but I soon found that no reliance whatever could be placed upon them. I also thought that the comparative merits of the two engines, and of the qualities of different varieties of coal, could be ascertained by simply taking the number of strokes made by the engine, and the weight of coals consumed, the only mode adopted for comparing one engine with another *on a large scale*[1] up to that time. The comparative qualities of the coals used for *this* engine would certainly have been ascertained in this way, so long as the load raised by the engine remained the same, the steam being cut off in the cylinder at the same portion of the stroke, and the experiments continued for a long period in order to obtain a fair average; but it would not have shown the value of the coals if applied to *another* engine *working under different circumstances:* even for this purpose I soon discovered, that placing reliance upon experiments of *short* duration would lead to most erroneous conclusions, which will be best shown by an example. The following detail is the duty done each 12 hours (excepting in one

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[1] See Lean's Monthly Reports of the Cornish Engines.

instance, that of the highest duty, which was for 6 hours only,) by the engine, coals from the same heap being used.

No. 1	74,414,043 lb. lifted 1 foot high per 94 lb. of coals.
2	101,631,419
3	76,229,503
4	109,161,312
5	63,650,298
6	73,966,672
7	90,317,262
[2] 8	118,522,475
9	72,980,766
10	83,908,876
11	73,800,374
12	95,027,040
13	69,027,779
14	102,807,378
15	70,141,833
16	108,093,258
Mean duty	86,480,018

From the foregoing example it will appear that the *highest* duty (which was taken for a period of 6 hours only) was 37 per cent. above the mean, and the *lowest* 26 per cent. below the mean.

Finding the disparity so very great in these experiments, I commenced a fresh series, with a view of ascertaining the actual evaporation of water with cylindrical and waggon-head boilers under different circumstances of surface exposed to the action of heat, of coals burnt per square foot of grate, of quantity of water evaporated, and, as regards the waggon-head boiler, *with* and *without* clothing: wishing also to ascertain the comparative merits of the two engines, I recorded the average quantity of water used per stroke in the form of steam.

The immortal James Watt, before he invented his improved steam engine, ascertained the quantity of water evaporated per lb. of coals consumed under the boiler, and the quantity of water used in the form of steam per stroke in the cylinder, of a Newcomen's Engine: to *him*, therefore, be it remembered,

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[2] Duration of experiment, 6 hours only.

we are indebted for the following excellent rules for determining practically the value of boilers and engines: viz.

To determine practically the superior economy of one boiler over another, the quantity of water evaporated per lb. of coals should be ascertained; and where experiments are made upon the *same* boiler, the *commercial* value of different varieties of coals may be most accurately determined.

To determine practically the superior economy of one mode of using steam over another, the quantity of water in the form of steam used per stroke should be ascertained.

MODE OF OBTAINING THE INFORMATION RECORDED IN THE FOLLOWING PAGES.

The dimensions of the boilers were obtained by simple admeasurement;[3] the water contents, and the space above the water level to the top of the man-hole, were ascertained by *weighing* water into the boilers to the two levels, and the ascertained weight in lb. divided by 62½ lb. gave the cubic contents.

To ascertain the quantity of water used by the high pressure or cylindrical boilers, a cistern was fixed near the air-pump cistern of the engine, and was gauged by *weighing* 21 cwts. of water into it, and marking the height of each cwt. upon a floating gauge-rod; it was filled through a pipe from the air-pump cistern, upon which was a stop-cock; the suction-pipe of the feed or hot-water pump communicated with this cistern, and the pipe to take off the surplus water of each stroke also communicated with it, so that whatever quantity of water was raised from the cistern by the pump over and above that required to supply the boilers returned into it again; when the cistern was emptied, no water was supplied to the boilers until it had again been filled to the exact level; the temperature of the water in the cistern was taken each time it was filled, and when it was nearly emptied; the mean temperature was considered the temperature of that cistern-full of water; the variation in temperature when the cistern was full and when nearly empty was never more than two degrees, and seldom more than one.

For the waggon-head boiler two cisterns were fixed adjacent to the feed-head; the first was supplied by the hot-water pump, and an overflow-pipe was

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[3] See Table No. I.

attached to it in the usual way; this communicated by a valve with the second cistern, which latter one was gauged by *weighing* water into it as previously described; it communicated freely with the feed-head, and the supply was regulated by the float in the boiler in the usual manner; when the cistern was emptied, the supply to the boiler was stopped until it was filled again to the proper level, and the temperatures were taken in the way already described.

In both cases the quantity of water supplied to the boiler every 12 hours was recorded. The supply of water to the cylindrical boilers was regulated in the manner that we always adopt, namely, by constantly admitting such a quantity as shall preserve the level of water as nearly as possible at the same height; this is done by the stoker working a system of levers communicating between the stoke-hole, and a cock which is fixed on the pipe that takes the surplus water from the feed-pump; he ascertains the height of the water in the boilers by means of glass gauges attached to each. It may here be remarked that the necessary attention to this keeps the stoker on the alert, and is, I consider, one of the best safeguards against accident from inefficient supply of water to high pressure boilers.

The coals were actually *weighed, not measured,* into the stoke-hole, and the surplus, if any, was also weighed at the end of every 12 hours.

A counter was fixed upon each engine, and the strokes made during every 12 hours were recorded.

The Tables referred to in the following remarks accompany this Paper, and at the end of each is an explanation thereof.[4]

The coals used during my experiments on both classes of boilers were *small* Newcastle coals, of the best quality, supplied by Mr. Charles William Tanner, of the Stratford Coal Wharf, Stratford.

As 80° Fahrenheit was about the mean temperature of the feed-water supplied to the cylindrical boilers during my experiments, I have adopted it as the standard temperature; and there is an advantage, I conceive, in this over a standard of 212°, because the temperature of the feed-water in engines generally is not much above 100°, and seldom below 80°; and, therefore, for ordinary purposes, the amount of evaporation, without going into calculations, will appear rather under-rated than over-rated in my Tables.

Although, for the sake of varying the proportions, I have tried and recorded

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[4] See Tables I. II. III. IV. V. VI.

experiments made on 2, 3, and 4 boilers used for generating steam for the same engine, I shall confine my observations to those upon the 4, as showing the greatest proportional difference in the two systems mentioned hereafter.

My experiments upon *four* Cornish boilers show that when the consumption of coals per square foot of grate per hour was only 2·475℔.,[5] and the water evaporated per hour equal to 23·5[5] cubic feet, 8·258℔.[5] of water were evaporated from 80° by 1℔. of coals; and when the coals per square foot of grate were equal to 5·013℔.,[6] or rather more than double, the water evaporated per hour being 47·8[6] cubic feet, or rather more than double, 8·605℔.[6] of water were evaporated from 80° by 1℔. of coals, showing an advantage of 4 per cent.[7] in favour of the more rapid combustion and evaporation. In both cases the same amount of boiler power was used; and be it observed, that 4 per cent. will be found to be a large proportion in reference to the experiments I am recording. In the experiments with the four boilers, it will be seen that greater effect was produced by rapid combustion and rapid evaporation than by slow combustion and slow evaporation.[8]

The following Table shows the *mean* results of *all* my trials upon *four cylindrical boilers*, lasting 504 hours for the quick combustion, and 514½ hours for the slow combustion.

	℔. of coals ꝑ hour.	Cubic feet of water ꝑ hour.	℔. of coals ꝑ sq. foot of grate ꝑ hour.	℔. of water evaporated ꝑ ℔. of coals from 80°.	Ratios.
Quick	342	46·9	4·682	8·524	100·
Slow	188	25·4	2·596	8·426	98·8

Now, with the *waggon-head boiler*, working in the day-time *only*, and not continuously night and day, as the cylindrical boilers were worked, and therefore under a disadvantage, as will be hereafter shown, when the consumption of coals *per square foot of grate per hour* was 10·89℔.[9] or 4⅓rd times greater

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[5] See Table V. Experiment 6, Columns 16, 19, 22.

[6] See Table V. Experiment 2, Columns 16, 19, 22.

[7] 8·258 : 8·605 : : 100 : 104·2.

[8] See Table V.

[9] Table No. V. Experiment 36. Col. 16, 19, 22.

In order to avoid any confusion of idea which might possibly result from the apparent disproportion of the above numbers, and those of the former experiment, to their respective products, it than in the first experiment noticed, and the water evaporated per hour was equal to 54·5 cube feet, or 2⅓rd times greater, 8·301 ℔. of water were evaporated from 80° by 1 ℔. of coals, or rather more than ½ (0·6) per cent.[10] in favour of the quick combustion and quick evaporation: if, however, the waggon-head boiler had been worked continuously, the evaporation of water per ℔. of coals from 80° would have been 8·448 ℔., or 2·38 per cent.[11] in favour of the quick combustion and evaporation.

The two experiments just referred to show the slowest and quickest combustion recorded by me; the trials have been made upon boilers required to do a certain daily duty, and to generate steam enough to supply their respective engines. I have not, therefore, had the opportunity of ascertaining the effect of *more* rapid combustion and evaporation; but the result of the *slow* combustion and evaporation shows that it was *too* slow for good working; to carry it to a greater extent would therefore, in my opinion, be useless.

The surface of boiler exposed to the action of the fire and heated air was equal to 588[12] square feet in the waggon-head, and 3192[12] square feet in the four cylindrical, boilers; the surface of the boiler over the fire was 40·42[13] square feet in the waggon, and 137·28[14] square feet in the cylindrical, boilers; the heated surface per square foot of grate was in the waggon 15·78[15] square feet, and in the cylindrical boilers 44·14[16] square feet.

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must be steadily borne in mind that there is a wide difference in the grate surfaces of the two boilers experimented upon, and that the quantity 10·89 ℔. is *rate*, while 54·5 cubic feet is an *absolute quantity*. This will be clearly understood from consideration of the following details.

Table V. Exp^t. 6.		Col. 7. Area of Grates.		Col. 16. Coals per sq. ft. of grate.		Col. 15. Coals consumed per hour.	Col. 19. Water evaporated per hour.	Col. 22. Water evaporated per ℔. of coals.
	Cylindrical slow combustion.	72·3	×	2·475	=	179	23·5	8·258
Do. Do. 36.	Waggon-head	37·26	×	10·89	=	406	54·5	8·301

[10] 8·301 : 100 : : 8·258 : 99·4, rather more than ½ per cent.

Col. 22.

[11] $$\left.\begin{array}{lll}\text{Table V.} & \text{Experiment 30.} & 7{\cdot}995\\ \text{Do.} & \text{Experiment 31.} & 7{\cdot}855\end{array}\right\} 7{\cdot}855 : 100 :: 7{\cdot}995 : 101{\cdot}78 \text{ and } 1{\cdot}78 + 0{\cdot}6 = 2{\cdot}38$$

100 : 8·301 : : 101·78 : 8·448.

[12] Table No. I. Col. 7.

[13] Table No. I. Col. 16.

[14] Table No. I. Col. 16. 35·10 + 33·80 + 33·28 + 35·10 = 137·28.

[15] Table No. V. Experiment 6, Col. 11.

[16] Table No. V. Experiment 36, Col. 11.

The *mean* of the results obtained from the use of the four cylindrical boilers, when the best evaporation in proportion to the coals consumed was obtained, was, as before shown, when the water evaporated was 46·9 cubic feet per hour, and coals consumed 342℔. per hour, and not when it was reduced to 23·5 cubic feet and 179℔. recorded as the slowest evaporation and combustion: to compare the slow system with the rapid it might hardly be considered fair to take the *slowest;* I shall therefore take 8·524℔.[17] of water evaporated from 80° per ℔. of best Newcastle *small* coals as the standard for the useful effect of the slow process, and 8·448℔.[18] of water evaporated from 80° per ℔. of best Newcastle *small* coals as the standard for the useful effect of the quick process: the advantage obtained by the slow process may then be taken as being equal to $\frac{9}{10}$ths per cent.[19]

The following are some of the proportions of the *two classes* of boilers to evaporate 1 cubic foot of water per hour from 80°.

Description.	Coals, ℔.	Square feet of heated surface.	Square feet of radiant heat surface.	Surface of grate.	Surface of air spaces in grate.	Proportion of air space in grate.	Square feet of heated surface per ℔. of coals.	Cubic contents of water.	Square feet of heated surface per cubic foot of water contents.	Weight of boilers in tons.	Weight in ℔.
Cylindrical	Slow 7·33	68	2·71	1·57	0·35	$\frac{1}{45}$	9·54	37·2	1·82	1·023	2292
Waggon-head	Quick 7·39	10.8	0·74	0·68	0·07	$\frac{1}{97}$	1·36	8·4	1·28	0·133	300

Now, after an examination of the second and last columns of this statement, I imagine an employer of boilers would prefer the quick combustion.[20]

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[17] See Table in page 8.

[18] See Note 11, page 9.

[19] 8·524 : 100 : : 8·448 : 99·1, or $\frac{9}{10}$ths per cent.

It will be perceived that, in speaking of *slow* and *slowest*, the terms are applied to the cylindrical boilers; and considering the *slowest rate* of combustion per square foot of grate disadvantageous, it was not thought fair to take it as the measure of effect of this *class* of boilers: I have therefore taken the *quick* combustion of that class, which may nevertheless be termed *slow* when compared with the other class, or waggon-head shaped boilers.

[20] The proportions of this Table, which are deduced from the mean results of the experiments, serve to show that a considerable outlay on materials may effect but a small saving in fuel; and if this saving should be less in value than the interest of the outlay, it would amount to an absolute loss.

An estimate of the cost of boilers and saving of coals will at once decide which is preferable. I shall take the waggon-head boiler, as made by Boulton and Watt, as the standard of one class; and, as it evaporated more water per hour than the four cylindrical boilers of the other class, the weight of the latter must be increased in proportion, to make a fair comparison for *useful*, or, in other words, *commercial* purposes. It should, however, be observed, that the comparative estimate will be but an approximation, as the cost of setting the boilers, and the cost of buildings, must depend upon the particular plans adopted by various engineers, and also upon the nature of the foundations; and again, the cost of both classes of boilers is taken at £27 per ton, although it is very likely the waggon-head boiler, even with a tube in it, might be made at a lower price: the omission, however, of these items is in favour of the cylindrical boilers.

One waggon-head boiler evaporated 54·5 cubic feet per hour, and weighed 7¼ tons. Four cylindrical boilers evaporated 46·9 cubic feet per hour (the most rapid evaporation), and weighed 48 tons. If 46·9 cubic feet required 48 tons of boiler, 54·5 cubic feet would require 55½ tons.

	£.	s.	d.
Cylindrical boilers, 55½ tons, at £27	1498	10	0
Waggon-head boilers, 7¼ tons, at £27	195	15	0
Difference	1302	15	0

Supposing the boilers are worked 365 days, the whole 24 hours, the coals consumed by the cylindrical will be equal to 1556 tons per annum, and by the waggon-head boiler 1569 tons, the saving in favour of the cylindrical boilers is equal to 13 tons of coals, which at 20*s.* is equal to £13.[21] It would be useless to continue the comparison of the *commercial* merits of the two classes of boilers farther; it must, however, be borne in mind, that one class of boilers is for high pressure steam, and the other for low pressure. The question whether it

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[21] If the comparison be drawn with the case of *slowest* (see Table V. Experiment 6, Cols. 16 and 19) evaporation by the cylindrical boilers, the outlay on the cylindrical boilers will appear as £3005. 2*s.*, and the difference as £2809. 7*s.*, and the *loss* of coals equal to £9. per annum. From this it appears, that under the notion of slow combustion being economical, if carried *too far* there will be a loss every way: 1st, a very great loss in outlay, and 2nd, a trifling loss in coals. The employer of a boiler would, therefore, do well to consult those who have practical knowledge of the effects, before he expends capital in altering the form of it with a view to economize fuel.

be necessary to have high pressure boilers for engines working expansively will be noticed in another part of this Paper. As regards *repairs* of boilers, as the expense cannot be estimated accurately, they are not taken into the account; and it may be assumed that the wear and tear in the one, due to the increased surface, is compensated for by its exposure to a much *less degree* of *heat*, while the other, although it has less surface, is exposed to a more intense heat.

It will be seen, by an examination of the Table[22] recording the experiments on the waggon-head boiler, that when the boiler and top of the flues were exposed, or *not* clothed, the evaporation was equal to 7·490 ℔. of water per ℔. of the best *small* Newcastle coals, and that when *well* clothed with *felt*,[23] the evaporation was increased to 8·301 ℔. of water per ℔. of coals of the *same* quality, showing a gain of $10\frac{8}{10}$ per cent., solely attributable to the use of good clothing.

In these experiments the engine was worked from 10 to 12 hours per diem only; if it had been worked the 24 hours round, as was the case during the experiments upon the cylindrical boilers, the evaporation per ℔. of coals would have been greater by 1·78 per cent.; for upon reference to the same Table it will be seen, when the boilers were clothed with five coats of hop-sacking, the engine working in the day *only*,[24] the evaporation of water per ℔. of coals was equal to 7·855 ℔., but when worked the 24 hours round,[25] it was equal to 7·995, or 1·78 per cent. greater, which, added to 10·8 per cent., will make a difference of evaporative power of $12\frac{1}{2}$ per cent. in favour of the same boiler when clothed, and working regularly the 24 hours through.

In all these experiments the water consumed during the night by condensation in the steam jacket, pipes, escape through safety-valve, and from other causes, and the coals used for banking up, were included, which will account for the gain when working 24 hours round.

A reference to the Table No. II., showing the evaporative power of different sorts of coals, will show that with the best Welsh coals I could obtain, 9·493 ℔. of water were evaporated per ℔. of coals; and with the best *small* Newcastle, 8·524 ℔. of water per ℔. of coals, showing a difference of 11 per cent.; but taking the average of the Welsh and small Newcastle coals, the difference

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[22] Table No. V. Experiment 27, Col. 22.

[23] Table No. V. Experiment 36, Col. 22.

[24] Experiment 31, Col. 22, and *vide* Note 11, page 9.

[25] Experiment 30, Col. 22.

was very trifling, but in favour of the latter.[26] It may here be observed that Mr. Watt, in the account of the qualities of coals (given in Dr. Robison's excellent treatise on the steam engine), speaks of "Swansea *or* Newcastle coals," as if *he* had considered them equal in quality.

To compare the results that I have arrived at with those of other experimenters, I am reduced to this strait, viz.: that few have been made for *useful* or *commercial* purposes upon which I can place reliance. It is much to be regretted that Smeaton and Watt did not leave a *detailed account* of evaporative experiments of *long* duration, but I have no doubt whatever they did make them, as they are the last men that could be suspected of jumping at conclusions upon slight grounds; the statements, therefore, made by them as to the evaporative power of their boilers may, I think, be unhesitatingly relied upon.

Assuming that the bushel of coals used by Mr. Smeaton weighed 84 ℔., then the evaporation with his boilers at Long Benton was equal (as calculated by Mr. Farey, in his excellent historical account of the steam engine,) to 7·88 ℔. of water per ℔. of Newcastle coals, which is equal to 7·385 ℔. from my standard of 80° Fahrenheit.

Mr. Watt's experiments at the Albion Mills show, according to Mr. Farey, that the evaporation from Newcastle coals was equal to 8·62 ℔. of water per ℔. of coals, or 8·446 ℔. from 80° Fahrenheit. Here again the weight of the bushel is supposed to be 84 ℔., thus:

				℔. of water from 80°.
Smeaton's boilers	. . .	in 1772	evaporated	7·385
Watt's	do.	in 1788	do.	8·446
Watt's	do. at Old Ford	in 1840	do.	8·301

Supposing these statements to be, as I have no doubt they are, accurate, would it be right to come to the conclusion that Mr. Watt, in 1788, (16 years after Mr. Smeaton's experiments,) had made a boiler that was $14\frac{4}{10}$ per cent. superior in evaporative power to Mr. Smeaton's?—and that in 1840, (52 years afterwards,) a boiler of the same construction, made at Watt's manufactory, should be reduced in value 2 per cent., the evaporative power

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[26] Table No. II. Mean of Welsh . . . . 8·045
Mean of small Newcastle . 8·074

being apparently only 12 $\frac{4}{10}$ths per cent. superior to Mr. Smeaton's boiler?

Unless the boilers had been clothed or protected from the atmosphere to the *same* extent, and the coals used under all the three classes had been taken from the *same* heap, and the experiments continued during a sufficiently long space of time to insure an average quality from the *same* heap, I do not think that any fair conclusions could be arrived at as to the comparative merits of these boilers as evaporative vessels; nor can we say that Mr. Watt at first made a boiler that was 14 per cent. superior to Mr. Smeaton's, or that 52 years afterwards a boiler of the same class should be 2 per cent. inferior in its evaporative power, and therefore that the boilers of the present day are worse than those made 52 years ago, especially when it is shown in Table No. II. that the *quality of coals* may vary 44 per cent.,[27] and that the mere circumstance of properly clothing increases the evaporative power of the same boiler nearly 11 per cent.[28] Smeaton's boilers were of the haystack form; Watt's first boilers waggon-head, *without* an internal tube, and the last *with* an internal tube.

There is no doubt that the area of the heated surface of a boiler, and the area of the grate, are important considerations in the construction of a good boiler and furnace; but, although the grate may be made too small, it may also be made too large; and again, a boiler may be constructed with the heated surface too small, and, as is proved by my experiments, too large. The quality of coals, the mode of stoking, the regularity in the work of the boiler, and protection from cold air, are also considerations of no small importance where economy is required. If, however, as in the locomotive engine boilers, circumstances do not allow you to have boilers of sufficient capacity; or, in other words, if the carrying an increased weight of iron and water requires a greater consumption of coals than is saved by the gain in evaporative power, it would be absurd to allow any favourite opinions

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[27] This great variation in the evaporative power of different kinds of coals would naturally suggest, even if it were not known to be a fact, that in the course of a long period of time a considerable change may take place in the quality of coal from the same pits, which may nevertheless have continued to bear its original *name*, which is generally derived from the locality where the mine is situated. This would appear to present a considerable chance of wrong conclusions in the comparison of the results of different experiments, made at long intervals of time.

[28] Table No. V.

to master your common sense. The same observations apply to marine boilers. As regards this latter class of boilers, the only experiment I am aware of for showing its evaporative power is recorded in the Appendix to Mr. Weale's splendid edition of Tredgold. Mr. J. Dinnen, assistant engineer in Her Majesty's Dock-yard, Woolwich, gives an account of a short experiment tried by him, showing the evaporative power of the boilers of the African steamer (page 24, Appendix). He states that, in December, 1831, 306 cubic feet of *fresh* water were evaporated in 6 hours at an expense of 24 cwt. of Heaton Main coal, equal to 7·115 ℔. of water evaporated per ℔. of coals; and assuming the temperature of the water, when admitted into the boiler, (being in the month of December,) to have been 40° Fahrenheit, the evaporation was equal to 7·358 ℔. per ℔. of coals from 80°; or 12·8 per cent. less than that of the Boulton and Watt boiler when well clothed; or 1·8 per cent. when *not* clothed. Now it *may* be assumed that if the *marine* boiler had been properly clothed, the gain in evaporative power might have been much greater than in the *land* boiler, the exposed surface in the former being much greater than in the latter; and again, it *may* be assumed that the coals were of different qualities, or that they were of the same. My own opinion, however, is, that the duration of the experiment was too short to enable any one to form an accurate opinion of the comparative evaporative power of the two classes of boilers.

As regards the evaporative power of the Cornish boilers, I have fortunately a more satisfactory series of experiments to compare my results with. It is stated by Messrs. Thomas Lean and Brother,[29] that in the last 6 months of the year 1838, the quantity of coals consumed by Loam's engine in the United Mines (diameter of cylinder 85 inches) was 700 tons, or 1,568,000 ℔., and the quantity of water injected into the boilers, and measured by an apparatus which, they state, correctly measures the quantity of water, was 234,210 cubic feet, or 14,638,125 ℔. of water: the evaporation was therefore equal to 9·335 ℔. of water per ℔. of coals.

My friend Mr. Enys, of Enys, took the temperature of the feed water of

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[29] Messrs. T. Lean and Brother are Registrars and Reporters of the duty of Steam Engines in the county of Cornwall, and have published a valuable work, compiled at the request of the British Association, entitled "An Historical Statement of the Improvement made in the Duty performed by the Steam Engines in Cornwall, from 1814 up to the present time."

this engine with many others in April, 1837, and found it to be 102°: assuming the temperature in the month of April to be the same as the average temperature of the 6 months, then the evaporation was equal to 9·159 ℔. of water per ℔. of coals from 80°. Now, if the Welsh coals used at the United Mines were equal in quality to those used by me, then it might be assumed that the evaporative power of the *boilers* used at Old Ford was $3\frac{6}{10}$ per cent. greater than of those used at the United Mines; but it may just as fairly be assumed that the *quality of coals* used by me was 7·2 per cent. superior to those used at the United Mines; and then, assumption upon assumption, it might be supposed that the United Mines' was $3\frac{6}{10}$ superior, instead of inferior: I, however, consider it most probable that so large a quantity of coals consumed during so long a period would be a fair average of the quality of coals used in Cornwall; and without taking for granted that the coals were superior to the general average, because the evaporation was to be publicly reported, the result of this valuable series of experiments may be adopted as the standard of the evaporative power of the generality of boilers in Cornwall using an average quality of Welsh coals. It will be seen by Table No. II. that 1 ℔. of Welsh coals, the worst tried by me, evaporated 7·155 ℔. of water, while 1 ℔. of the best Welsh coals, bought in London, evaporated 9·493 ℔. of water,—a difference equal to 32 per cent., sufficiently proving the absurdity of comparing experiments tried upon different classes of boilers with different qualities of coals. Supposing that in one class of boilers the *Welsh* coals had evaporated 7·155 ℔. of water, and in another 9·493 ℔. of water, would it have been fair to assume, that because the coals were called *Welsh*, they were therefore equally good in quality?—if so, then you might assume that one class of boilers was 32 per cent. superior in evaporative power to the other; but as it has been already shown that this difference exists in coals of the *same name*, used under the *same* boilers, and working the same engine, this conclusion as to the comparative merits of the boilers would have been very erroneous.

While on this subject, it may be well to state, that in my trial of the Holmbush engine the object was, first, to show the general superiority of the expansive system over the non-expansive. I compared the work done by this engine during a very short trial with the work done by the other class of engine in a still shorter trial; it showed generally that which it was intended to do, namely, that one mode of *using* the steam was far more economical than the other: my next object was to ascertain the actual weight of water lifted, but I had no idea whatever of determining the evaporative power of the boiler, or that, from such an experiment, data could be obtained for the foundation of a theory for expansive engines.

It must always be borne in mind that the coals used in Cornwall are *measured*, and *not weighed;* and although Captain Lean, than whom no one has had greater experience, has stated that the average weight of a bushel, as used in Cornwall, is 93 or 94 ℔.,—and for the general object of the monthly reports this may be a sufficient approximation,—it is not so for forming nice calculations on the evaporative power of either boilers or coals. In the celebrated trial of the Fowey Consols Engine, the Committee stated that 28 bushels of coals were *measured* in their presence, and that "*a* bushel" of coals was *weighed*, and found to be 94 ℔. I consider this mode of proceeding was sufficiently accurate for the purpose; it was the *usual mode adopted in the County;* but they did not state, nor did they ascertain, what was the *quality* of the coals used: it is possible that the coals used may have been inferior to the average, but I think it more probable they were superior.

In 1838, I was requested by the Council to obtain information as to the weight of coals. Mr. Nicholas Harvey then favoured me with the following statement, which is reported in the minutes of conversation for 1838, that "the weight of a bushel of Welsh coals varied from 80 ℔. to 112 ℔."[30] Now, although I have before stated, that the reports of the duty done by the Cornish Engines answered well the purpose they were intended to effect, nevertheless, so long as the exact weight of the coals consumed, and the water evaporated, is not registered accurately, I should not rely upon these statements in making calculations upon the comparative merits of boilers, even though the coals used might, in both cases, be of the same name.

As regards the mode of measuring the water by the number of strokes of the feed-pump, I have found that when the one at Old Ford is in good order, the actual delivery is within 1·66 per cent. of the theoretical delivery; but as the engine seldom makes two successive strokes of exactly the same length, unless the length of each stroke be taken during the time it is supplying the boiler, the *exact* quantity will not be ascertained: supposing the variation of the

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[30] This statement shows how little reliance can be placed upon the results of trials where the coals are *measured*, and not *weighed;* if the measure is made large enough to hold 112 ℔. of coal, it should no longer be denominated a *bushel*.

one at Old Ford to be $\frac{1}{2}$ an inch, the difference would be $\frac{1}{60}$th, or 1·66 per cent. loss; the two together would be equal to 3·32 per cent., and this is upon the assumption of the pump being in the very best order: if in bad order, (and as the pump is always capable of raising more water than is required to feed the boilers, it may be so without rendering it necessary to stop the engine to repair the valves or pack the plunger,) calculations on evaporation under such circumstances must be very erroneous.

Again, unless the level of the water in the boiler is taken very accurately at the commencement and termination of a trial,—and in a high pressure boiler practical men know this to be a most difficult thing to do, if not an impossibility, owing to the violent ebullition,—the results, either of duty or evaporation, will be most erroneous; you may either be in excess or the reverse, and this might not be dependent on the honesty of the experimenter, but on the mode of conducting the experiment.

As regards the proportions for boilers, Boulton and Watt's proportions are, as far as my experience extends, the best for generating low pressure steam; and with regard to high pressure steam, as I have tried experiments on one form of high pressure boiler only, I cannot say what proportions are best,[31] thinking, as I do, that rules for these proportions should be founded upon correct experiments, and not upon theories derived from the results of experiments tried upon different forms of boilers, unless used for the same purposes, and belonging to the same class, whether high or low pressure, land, marine, or locomotive, as in all these cases other objects besides economy in fuel, as regards the boiler itself, may have to be considered; and in all questions of economy of fuel, the weight and cost of the boiler, so modified as to effect the proposed economy, must also be considered.

From the foregoing statement it would therefore appear that very little, if any, improvement has been made in the evaporative power of boilers since the days of the great, the immortal, JAMES WATT!

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[31] If the proportions of the waggon-head boiler produce the greatest effect with the least weight of boiler, then, although for steam of high pressure it may, for the sake of strength, be necessary to alter the *form*, it does not follow as a consequence that the *proportions* of water contents, heating surface, grate surface, &c., should also be altered.

PART II.—ON ENGINES.

It will be seen by an examination of Table No. VII., lines F and H, column 34, that the useful effect produced by the Cornish Engine is equal to a duty of 97,146,268 ℔. raised 1 foot high by the consumption of 1 cwt. of small Newcastle coals, or 108,198,102 ℔.[1] raised 1 foot high by the consumption of 1 cwt. of best Welsh coals; and that by the Boulton and Watt Engine is equal to a duty of 42,847,598 ℔. with small Newcastle, or 47,718,084 ℔. with best Welsh coals: the difference between the two engines is great, the Cornish producing 2¼ times the effect of the Boulton and Watt.

Duty of Boulton and Watt.		Duty of Cornish.
42,847,598 : 100	: :	97,146,268 : 226

I shall endeavour to show to what this difference is attributable.

It is assumed that the same quantity of water is evaporated per ℔. of coals under both classes of boilers, viz., 8·524 ℔. of water by 1 ℔. of small Newcastle coals, and that both are worked the 24 hours round. The loss at night in the Boulton and Watt Engine, when not at work, is equal to nearly 2½ per cent.; the quantity of water in the form of steam thus wasted is given in the explanation to line H, Table No. VII.

The difference in the effect produced by the two classes of boilers working the 24 hours has already been shown to be about $\frac{9}{10}$ths per cent. in favour of the Cornish; but these two points must not be taken into account in the following pages, as the question is—as to the comparative merits of the two *engines, not* the *boilers.*

The following are the principal points of difference between the two Engines:—

1st. The cylinder in the Cornish Engine is fixed in such a position relative to the boilers, that the condensed steam, if any, in the jacket, can return into the boiler. The jacket is so well cased that the steam is not lowered in temperature more than 7 degrees of Fahrenheit (temperature in boiler 284°,

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[1] Table No. VII., Column 36.

in jacket 277°,)[2] and the water used in the form of steam for this purpose is calculated at 0·028 ℔. per stroke (see Note 8, Table No. VII.), or about $\frac{1}{2}$ per cent. of the whole quantity used.

In the Boulton and Watt Engine the condensed steam runs off through a syphon, and does not return into the boiler; the *whole* is therefore lost; it amounts to 0·099 ℔. of water in the form of steam per stroke, or about $2\frac{2}{10}$ per cent. of the whole quantity used.

Deducting one from the other leaves $1\frac{7}{10}$ per cent. excess of loss in the Boulton and Watt Engine.[3]

2nd. The space above the piston in the Cornish Engine, when out of doors, is equal to 18 cubic feet, or about $\frac{1}{20}$th of the space *above* the piston when in doors; in the Boulton and Watt Engine it is equal to 20 cubic feet, or about $\frac{1}{8}$th; the equilibrium valve is fixed near the *bottom* of the cylinder in the Boulton and Watt Engine, and communicates with the top of the cylinder by means of a pipe; if the valve were fixed at the *top*, as in the Cornish Engine, the steam-space would be reduced to 14 cubic feet, or about $\frac{1}{12}$th.

In a *single* engine, where the top of the piston has no direct communication with the condenser, if the steam were used without expanding, or, in other words, if the pressure were the same throughout the stroke, no loss would be sustained in consequence of this space; but when the steam is used expansively, or when the pressure at the commencement of the stroke is greater than at the end, then, before the steam-valve is opened, this space is filled with steam of less density than that about to be admitted, and consequently a space proportionate to the difference of the densities has to be charged with steam, and of course the more expansively the steam is worked, the greater the quantity of steam to fill this space, to be so charged, will be, as the steam remaining upon the top of the piston, after the previous stroke, will be more rare, or of less density: now the steam that *is* left acts again, and is therefore useful. In the case now before us the steam left in the Cornish cylinder would occupy, when compressed into a volume of the density of the

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		℔.	temp.
[2] Column 5. Table VII., line F,	pressure in boiler . .	51·7	284°.
7. Do. do.	steam jacket	45·7	277°.

[3] If the cylinder and boilers were arranged as the Cornish are, the casing round the steam jacket being, as it is supposed, equally effective, this loss would not be sustained.

steam about to be admitted, a space equal to 7·76 cubic feet, or nearly $\frac{1}{16}$th of the whole space above the piston at the instant of cutting off the steam.[4] The steam left in the Boulton and Watt cylinder would occupy a space equal to 11·95 cubic feet, or about $\frac{1}{10}$th of the whole space above the piston,[5] at the instant of cutting off the steam.

It must not, however, be assumed from the foregoing statements, that when steam is worked expansively an increase of space above the piston, when in doors, is advantageous. Suppose the space in the Cornish to be as great in proportion as the Boulton and Watt, namely, $\frac{1}{8}$th instead of $\frac{1}{20}$th of the whole contents when the piston is in doors; then the steam-space would be equal to 45 cube feet, and the space occupied by the steam left in the cylinder at the end of the previous stroke, when the steam-valve is opened, would be 19·4; the difference is 25·6. In the previous case the steam-space was 18 cube feet, and deducting 7·76 steam left in cylinder, the difference is 10·24: now the additional steam required each stroke to produce the same effect is equal to (25·6−10·24=) 15·36 cube feet, or about 12½ per cent. *more* steam per stroke than when the steam-space above the piston in the outdoor stroke was less. Again, supposing the steam-space in the Boulton and Watt Engine had been in the same proportion as in the Cornish, namely, $\frac{1}{20}$th instead of $\frac{1}{8}$th, or equal to 7·7 cube feet, then the space occupied by the steam left in the cylinder upon the opening of the steam-valve would be equal to 4·6 cube feet; the difference is 3·1 cube feet instead of (20−11·95=) 8·05; it would therefore require (8·05−3·1=) 4·95 cube feet, or about 4¼ per cent. *less* steam per stroke to produce the same effect.

Thus the loss in the Boulton and Watt Engine, from the disposal of the jacket-steam and large steam-space above piston, is equal to ($1\frac{7}{10}$ per cent. +4·2 per cent.=) nearly 6 per cent., or, in other words, if the arrangements in respect to these two points were similar to those in the Cornish Engine, the duty would have been 45,418,453℔.[6] lifted 1 foot high per

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[4] Table VII., line F.—$\overset{\text{Column 16.}}{20{\cdot}17\text{ ℔.}} \;:\; \overset{\text{Column 10.}}{18} \;::\; \overset{\text{Column 11.}}{8{\cdot}7} \;:\; \overset{\text{Cube ft.}}{7{\cdot}76}$ and $\overset{\text{Column 15.}}{\frac{127}{7{\cdot}76}} = 16.$

[5] Table VII., line H.—$\overset{\text{Column 16.}}{17{\cdot}15} \;:\; \overset{\text{Column 10.}}{20} \;::\; \overset{\text{Column 11.}}{10{\cdot}25} \;:\; \overset{\text{Cube ft.}}{11{\cdot}95}$ and $\overset{\text{Column 15.}}{\frac{117{\cdot}5}{11{\cdot}95}}$ = 9·83, say 10.

[6] 100 : 42,847,598 :: 106 : 45,418,453.

cwt. of *small* Newcastle coals; and the Cornish Engine would then have produced only 2·13 times the effect, instead of 2·26 times.

As regards the propriety of making these alterations in the Boulton and Watt Engine, there can be no doubt about the first; and as regards the second, the alteration in the position in the equilibrium valve would, as already shown, reduce the space above the piston considerably, and advantageously; but the height to which it would be safe to allow the piston to rise in the cylinder, in the out-door stroke, is a question of prudence. When allowed to rise as high as it is in the Cornish Engine, it is very requisite to have strong and stiff spring beams to prevent the cylinder cover being struck.

3rd. The next point to be considered is the difference in the resistances that each has to overcome, which will be best shown in the tabular form. The resistance offered to the steam power in the Cornish Engine varies during the stroke, because the water is raised from the well into the pump-barrel, and the air-pump is worked, by the in-door stroke; in the Boulton and Watt Engine the reverse is the case.

	Cornish Engine						Boulton & Watt Engine	
	at beginning of stroke.		at end of stroke.		average		average	
	whole load in ℔.	℔. ⅌ sq. inch on piston.	whole load in ℔.	℔. ⅌ sq. inch on piston.	whole load in ℔.	℔. ⅌ sq. inch on piston.	whole load in ℔.	℔. ⅌ sq. inch on piston.
Preponderating weight outer end of beam	55401	11·037	55401	11·037	55401	11·037	5956	2·120
Water load raised by engine	1804	0·359	6446	1·284	4125	0·821	25942	9·235
Cold-water pump	186	0·037	186	0·037	186	0·037	294·5	0·104
Hot-water pump	3	..	9	..	6	..	53·5	0·019
Air-pump	86	0·017	6720	1·338	591	0·117	0·	0·
Friction	1009	0·200	1009	0·200	1009	0·200	1359	0·483
Imperfect vacuum	3664	0·730	3664	0·730	3664	0·730	1376	0·490
Total	62153	12·380	73435	14·626	64982	12·94	34981	12·451

The mean load actually lifted, or preponderating weight and water, by the Cornish is equal to (11·037 + 0·821 =) 11·858℔. per square inch of the piston; and by the Boulton and Watt Engine (2·12 + 9·235 =) 11·355℔. per square inch of piston.

The *useful effect* is thus obtained: the diameter of the plunger of the Cornish pump is 41 inches, area 9·168 square feet; the water is raised 108 feet from the surface in the well; the stroke is 9 feet, while the stroke of the engine is 10 feet; the area of the piston, minus the area of the piston rod, is equal to 5019 square inches.

$$9{\cdot}168 \text{ sq. ft.} \times 108 \text{ ft.} \times 62{\cdot}5 \text{ ℔.} = 61884 \text{ ℔.}$$

$$61884 \text{ ℔.} \times \frac{9 \text{ ft. pump stroke}}{10 \text{ ft. engine stroke}} = 55695{\cdot}6 \text{ ℔. load on piston.}$$

$$\frac{\text{Load on piston}}{\text{Area of piston}} \quad \frac{55695{\cdot}6 \text{ ℔.}}{5019{\cdot}5 \text{ sq. in.}} = 11{\cdot}09 \text{ per square inch of piston.}$$

The diameter of the Boulton and Watt pump is 27⅛ inches, and the pump rod 4⅞ inches; area, minus area of pump rod, equal to 3·88 square feet; the water is raised, 107 feet from the surface in the well; the stroke is 7·91 feet; area of piston, minus area of piston rod, is equal to 2809 square inches.

$$3{\cdot}88 \text{ sq. ft.} \times 107 \text{ ft.} \times 62{\cdot}5 \text{ ℔.} = 25947{\cdot}5 \text{ ℔. load on piston.}$$

$$\frac{\text{Load on piston}}{\text{Area of piston}} \quad \frac{25947{\cdot}5 \text{ ℔.}}{2809 \text{ sq. in.}} = 9{\cdot}23 \text{ ℔. per square inch of piston.}$$

In the Cornish Engine the useful effect is (12·94 : 100 : : 11·09 :) 85·7 per cent. of the whole resistance, *including imperfect vacuum*, or (12·21 : 100 : : 11·09 :) 90·8 per cent. exclusive of it.

In the Boulton and Watt Engine the useful effect is (12·45 : 100 : : 9·23 :) 74 per cent. of the whole resistance, *including imperfect vacuum*, or (11·96 : 100 : : 9·23 :) 77 per cent. exclusive of it.

The sum of the resistances in the Cornish Engine, over and above the useful effect, is equal to (12·94 − 11·09 =) 1·85℔. pressure per square inch, or, *minus imperfect vacuum* (1·85 − 0·73), 1·12℔.; and in the Boulton and Watt Engine (12·45 − 9·23 =) 3·22℔. pressure per square inch, or, *minus imperfect vacuum* (3·22 − 0·49 =), 2·73℔.; the resistance in the Boulton and Watt Engine arising from a different arrangement of the machinery is, therefore, equal to (2·73 − 1·12 =) 1·61℔. pressure per square inch more than in the Cornish. Now, if the arrangements were similar, the duty done by the Boulton and Watt Engine would have been (9·23 : 45,418,453 : : $\overbrace{9{\cdot}23 + 1{\cdot}61 :)}$

53,340,848 lbs. lifted 1 foot high per cwt. of small Newcastle coals; and the Cornish Engine would have produced only 1·82 times the effect of the Boulton and Watt Engine.

4th. From the foregoing analysis it appears that the gain *by working more expansively* is as 100 : 182.

An examination of column 23, Table VII., will show that as the engines were worked more expansively, the excess of pressure above the resistances was greater: it must be remembered that the load remained the *same*, and therefore to give sufficient momentum to enable the engine to perform the whole stroke, it would require a greater pressure at starting in proportion to the greater distance the piston would have to travel after the steam was cut off. It is supposed that if the load had been reduced as the expansive working was increased, it might have been so proportioned that the excess of pressure at the commencement of the stroke in each case might have been the same.

It may be well here to observe upon the ordinary working of a mining engine. When the engine is first erected, the load to be lifted is very trifling in proportion to the capabilities of the engine, and consequently the steam *may* be cut off even at $\frac{1}{10}$th of the whole stroke, as I am informed has been the case in some instances: under such circumstances the duty performed by the engine would be very great. As, however, the mine deepens, and the quantity of water increases, the load upon the engine is increased, and consequently more steam is required; it cannot, therefore, be cut off so soon, and the duty of the engine consequently decreases, and might continue to do so if the load were increased until it required steam during the whole stroke to overcome the increased resistance. The obvious reason for the falling off of the large duties after some years working of the engine (so often noticed), is, not that the engine itself has deteriorated, but that its actual power, when working so very expansively, is so small in proportion to the size, that the interest upon the outlay and the cost of working an increased number of engines, which would be required to preserve the same rate of duty, would counterbalance, if not far exceed, the value of the saving in fuel: thus the same argument will hold good for the engine as for the boiler.

It must be remembered that the trials made at Holmbush and at the Fowey Consols were upon engines that had not been long erected, and where the load to be lifted was light in proportion to the size of the engine; and this will perhaps be better understood when I mention that the diameter of the cylinder in the first was 50 inches, stroke 9 feet 1 inch, and power $26\frac{1}{2}$ horses; the second cylinder 80 inches, stroke 10 feet 4 inches, and power 62 horses.[7]

An approximate calculation of the work done by the two engines while under trial, upon the best data in my possession, is given below and in Table No. VII.,[8] showing that, with coals whose evaporative power was, as

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[7] See Appendix.

[8] *Fowey Consols Engine.*

Data.—Cylinder, 80 inches diameter; stroke, 10·33 feet; area, 34·6 square feet, or 4988 square inches.

Stroke outer end of beam, 9·25 feet.

Absolute pressure of steam in boilers, 55·2 ℔.

Water load, 51626 ℔. Water evaporated, 10·23 ℔. per ℔. of coals, according to Mr. West.

Steam-space above piston, taken as at Old Ford, 18 cube feet.

Water load (10·33 : 9·25 : : 51626 :) 46228 ℔. on piston.

Useful effect $\frac{40311 \text{ ℔. actually raised*}}{4988} = 8\cdot081$ ℔. pressure per square inch of piston.

Resistances.

Water load . . . . . . $\frac{46228}{4988} = 9\cdot267$ ℔. per square inch of piston.

Air-pump, as at East London Water-Works, 0·117

Friction, calculated as twice that of the engine at the East London Water-Works } 0·400

Imperfect vacuum . . . . 0·730

Total . . . . 10·514

N.B.—No cold-water pump; water supplied from the mine for condensation.

Steam cut off at $\frac{1}{4}$th of the stroke, as stated by Mr. West.

$$\frac{\overset{\text{area of piston}}{34\cdot6} \times \overset{\text{stroke}}{10\cdot33}}{4} = 89\cdot35 + \overset{\text{steam space.}}{18} = 107\cdot35$$ cube feet space above piston when steam-valve is closed.

The engine made 6287 strokes with the consumption of 2256 ℔. of coals.

$$\frac{\overset{\text{℔. water per ℔. of coals.}}{10\cdot23} \times \overset{\text{℔. coals.}}{2256}}{6287 \text{ strokes}} = 3\cdot67$$ ℔. or 0·0587 cube foot water per stroke as steam.

For *Results*, see Table No. VII. (*in red ink*).

* The actual water raised as found by me at Holmbush was 14·7 per cent. less than what was due to theory, or to the mode adopted in the Cornish reports.

stated by Mr. West, equal to 10·23 lb. of water per pound of coals, the duty stated to have been performed *might* have been done, *there being steam power sufficient to overcome the resistances.*

In the second Paper I presented to the Institution upon this subject, dated August 7th, 1837, it would appear that the friction of the Holmbush Engine was equal to 7¾ lb. per square inch, exclusive of imperfection of vacuum: *this is incorrect;* my subsequent experience convinces me that the data supplied to me, and the mode I adopted in calculating, were both inaccurate. The data

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Holmbush Engine.

Data.—Cylinder, 50 inches diameter; stroke, 9 feet 1 inch; area, 13·6 square feet, or 1963·5 square inches.

Stroke outer end of beam, 8 feet 1 inch.

Absolute pressure of steam in boilers, 54·7 lb., as stated by Mr. West.

Water load, 21·706 lb.; water evaporated, 10·23 lb. per lb. of coals, according to Mr. West.

$$\text{Steam-space above piston } (\overset{\text{area of 80 in.}}{5058} : \overset{\text{cube ft.}}{18} :: \overset{\text{area of 50 in.}}{1963\cdot5} :)\ 7 \text{ cube feet.}$$

$$\text{Water load } (\overset{\text{cyl. stroke.}}{9\cdot08} : \overset{\text{pump stroke.}}{8\cdot08} :: \overset{\text{lb.}}{21706} :)\ \overset{\text{lb.}}{19315} \text{ upon piston.}$$

Useful effect water actually raised 18928 lb., or 9·08 : 8·08 :: 18928 : 16843.

$$\frac{16843}{1963} = 8\cdot58 \text{ lb. per square inch of piston.}$$

Resistances.

Water load . . . . . . $\frac{19315}{1963}$ =	9·839 lb. per square inch of piston.
Air-pump, $80^2 : 50^2 :: 0\cdot117$:	0·045
Friction calculated as twice that of the engine at the East London Water-Works	0·400
Imperfect vacuum	0·730
Total	11·014

N.B.—No cold-water pump; water supplied from the mine for condensation.

Steam cut off at ⅙th of the stroke, as stated by Mr. West.

$$\frac{\overset{\text{sq. ft.}}{13\cdot6} \times \overset{\text{ft. stroke.}}{9\cdot08}}{6} = 20\cdot58 + \overset{\text{steam space.}}{7} = 27\cdot58 \text{ cube feet space above piston when steam-valve is closed.}$$

The engine made 672 strokes with the consumption of 94 lb. of coals.

$$\frac{\overset{\text{lb. water per lb. of coals.}}{10\cdot23} \times \overset{\text{lb.}}{94}}{672 \text{ strokes}} = 1\cdot43 \text{ lb., or } 0\cdot0228 \text{ cube foot water per stroke as steam.}$$

For *Results*, see Table No. VII. (*in red ink*).

were supplied by the engineer of the mine, and the mode of calculating copied from Mr. Watt.[9]

From the facts regarding friction which I have obtained during the last three years, it appears that the friction, including also all resistances excepting useful effect, could not have very much exceeded 2·434 ℔. per square inch, including imperfection of vacuum; and, again, in the first Paper presented, dated November, 1835, the friction of a water-works engine, including all resistances excepting imperfection of vacuum and useful effect, is stated as equal to 5·65 ℔. pressure per square inch: in this case it was assumed that the pressure of steam in the *cylinder* throughout the *whole* stroke was the same as that in the *boiler*, and therefore the calculation was incorrect. It appears from my late experience that the whole amount of friction, including imperfection of vacuum, does not, in the Boulton and Watt Engine, exceed 3¼ ℔. The rules adopted by me were those generally followed at the time: more experience has been obtained in these matters since the commencement of the discussions at the Institution of Civil Engineers, which my Paper of November, 1835, originated; and if any good has been done to science by the introduction of these discussions, much of the credit is due to the President, who strongly urged the presentation of my first imperfect Paper.

As regards the pressure of steam being so much higher in the Cornish *boilers* than it is when introduced into the *cylinder*, I have merely to observe, that the cylindrical form of boiler is such as to allow but little steam-space, and therefore it is necessary to increase it by having the space filled with steam of greater density; and from the small size of the steam-valves and port-holes in the engine under discussion, increased pressure is required to allow a sufficient quantity of steam to pass into the cylinder during the time the steam-valve is opened. In practice, when high pressure boilers are employed, it might be dangerous to have the steam-valve very large, as in case of the pressure being much increased in the boilers, the increased effect upon the piston, when the admission was unchecked by wire-drawing, might lead to an accident. I can, however, see no reason why, if the steam-space in the

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[9] The error in the *calculation* arose from its being assumed that the elasticity of the steam, as it expanded, was directly as its density, AFTER the communication with the water in the boiler had been cut off, by closing the steam-valve.

boilers were larger, and the valves and pipes increased in size, the pressure of steam in the boilers might not be less.

As regards the steam left on the top of the piston at the end of the out-door stroke, it will be seen that it is only equal to about 6¾ ℔., while the preponderating weight on the outer end of the beam is equal to 11 ℔.: now, if this preponderating weight were unbalanced and unchecked, the cylinder cover would, of course, be broken; but, first of all, there is the column of water which counterbalances the preponderating weight, and should this column be less in height than is required to balance the 4 or 5 ℔. excess, then the catches on the beam will rest upon the spring beams before the piston has reached the cylinder cover. I am at a loss to understand the meaning of the phrase "cushion," as applied to the steam in the space above the piston, as of itself, it is not sufficient to oppose the preponderating weight, and in fact it is not required to do so.

When the mercurial gauge was applied to the top of the cylinder it was found that the mercury suddenly rose above the pressure that it was presumed was necessary to work the engine, and above that which was due to the calculated density of the admitted steam; and it was also found that at the end of the stroke the pressure indicated was frequently 1 ℔. or 2 ℔.[10] *below* a perfect vacuum. The mercurial gauge, as a practical indicator of the pressure during the stroke, was therefore rejected, as it was assumed that the sudden change in pressure caused the mercury to jump above and below the *real* pressures; but, as it was found upon holding the engine in doors that the actual pressure was 6 or 7 ℔. above a perfect vacuum instead of 1 or 2 ℔. below, which in fact would have been an absurdity, the rule adopted was this: to determine the pressure of the steam while the communication with the boiler was free, or, in other words, the steam-valve open, (the water in the form of steam being *known*,) the density of the steam was either calculated, or taken from the Count de Pambour's Tables; and the pressure at the end of the in and out-door strokes was ascertained by holding the engine in hand, and allowing the mercury in the gauge to settle; and this showed that when the communication with the boiler was shut off, the pressure was reduced

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[10] Every employer of a condensing steam engine must have observed this effect, which is always produced when the cock communicating between the condenser and barometer is opened too suddenly.

below that which would have been due to its expansion if communicating freely with the water in the boiler. This is more fully explained in the Notes to Table No. VII.

The only point, as far as I am aware, that is not already explained, either in this Paper or in the Tables and Explanations attached to them, is that of the term friction, in the Table, page 22. The amount was thus ascertained in both engines. The preponderance of the outer end was obtained by unpacking all pistons, buckets, and stuffing boxes, and the beam was then weighed by steel-yards attached to the outer end; this weight was ascertained *before* the load was added, which was afterwards accurately weighed to half a pound in my presence. Then, as it is certain that the only power to carry the engine out of doors was this preponderating weight, the weight required to balance the column of water in the Cornish Pump, and to work the feed-pump, was abstracted from the *total* weight,—and the difference was friction; and in the Boulton and Watt Engine, the weight required to lift the water from the well into the pump, and to work the air-pump, was abstracted from the *total* weight,—and the difference was friction.

APPENDIX.

A GREAT many remarks have been made of late years upon the terms 'horse power' and 'duty.' The first is used by engine manufacturers generally to describe the size of their engines, and the latter by the Cornish engineers to describe the relative work done by their engines. Thus, an engine manufacturer makes an engine, and, according to the diameter of the cylinder, he calls it a certain number of *horses' power*, and a Cornish engineer tells you one engine is superior to another *because* it does more '*duty*,' that is to say, produces a greater effect with a given consumption of fuel.

There is no objection, in my opinion, to these terms, if well understood; but as this does not appear to be the case, it may be worth while to give some explanation of them.

I imagine the proper meaning of the term 'horse power' is this,—that an engine of one horse power is capable of raising 33000 lb. one foot high in one minute, *in addition* to the power necessary to overcome the friction and work it; in other words, the *useful effect* must be equal to 33000 lb. lifted one foot high in a minute.

This may be illustrated by a calculation of the horse power of the two engines upon which my experiments have been tried.

1st.—THE CORNISH.

Data.

Area of piston minus area of piston rod . . . . . = 5019 square inches.

The useful effect produced, or the water actually raised, is equal to 11·09 lb. upon every square inch of the piston; therefore the effective pressure will be . . . . = 11·09 lb.

Length of stroke of piston . . . . = 10 feet.

Number of strokes per minute . . . . . . = 8

Calculation.

sq. in. lb. lb.
5019 × 11·09 = 55660·71 weight to be lifted.
10 feet × 8 = 80 feet; height lifted in 1 minute.
55660·71 × 80 = 4452856·8 lb. lifted 1 foot high in 1 minute.

$$\frac{4452856{\cdot}8}{33000} = 134{\cdot}93, \text{ or nearly 135 horses' power.}$$

In 1839 and 1840, *this* engine worked frequently 11 and 12 strokes per minute, and the power when working 12 strokes per minute was equal to 202·39 horses. It has, however, been considered most prudent to reduce the speed to 8 strokes, on account of the great wear and tear and liability to accident that is incurred by working so large an engine at too great a speed.

The circumstance just mentioned shows how easily an error may be made in speaking of the *horse power* of an engine. One person may have observed the engine working at the rate of 6 strokes per minute, while another may have noticed it when it was working at 12 strokes per minute: the results they would have arrived at, if they had calculated its power, would of course have varied in the proportion of 1 to 2; the first would have called it 101 horses' power, the latter 202 horses' power: although the diameter of the cylinder, length of stroke, and pressure per square inch were the same, the number of strokes was different. In speaking, therefore, of an engine similarly arranged, that is to say, where the load to be lifted is always the same, no mistake could be made if the power for *one stroke per minute* were given, namely, 16·86 horses' power; this might be multiplied by the number of strokes per minute, which would be regulated by the work required and the judgment of the employer of the engine.

2nd.—THE BOULTON AND WATT.

Data.

Area of piston minus area of piston rod . . . . . = 2809 square inches.
The useful effect produced, or the water actually raised, is equal to 9·23 ℔.;
the effective pressure will be . . . . . . = 9·23 ℔.
Length of stroke of piston . . . . = 7·91 feet.
Number of strokes per minute . . . . . . = 11·5

Calculation.

sq. in. ℔. ℔.
2809 × 9·23 = 25927·07 weight to be lifted.
7·91 feet × 11·5 = 90·965 feet; height lifted in 1 minute.
25927·07 × 90·965 = 2358455·9 ℔. lifted 1 foot high in 1 minute.

$$\frac{2358455{\cdot}9}{33000} = 71{\cdot}46, \text{ or nearly } 71\tfrac{1}{2} \text{ horses' power.}$$

The power of this engine at one stroke per minute will be equal to 6·21 horses.

Proportions.

The areas of the cylinders are as 5019 : 100 : : 2809 : 55·9
The power of the engines is as 134·93 : 100 : : 71·46 : 52·9

From the foregoing statement it appears, in this instance, that the power of the engines, when working at their proper speed, is nearly in proportion to the areas of their cylinders.

Thus it will appear that so long as the standard of a horse's power is taken as equal to 33000 ℔. lifted one foot high per minute, and the useful effect produced is *ascertained*, as in the foregoing examples, it is a good rule for obtaining a fair mode of arriving at the different powers of engines; but if this mode of calculating be not strictly adhered to, the result will be but an approximation. If, for instance, it is assumed that the useful effect is ⅔rds of the whole power exerted by the steam, allowing, as is not uncommonly done, ⅓rd for friction, &c., the mean pressure of the steam in the Cornish Engine being equal to 15·54 ℔., and in the Boulton and Watt 12·56 ℔., then (15·54 × ·66 =) 10·25 ℔. would represent the effective pressure of the Cornish Engine: the *ascertained* effective pressure was however 11·09 ℔. per square inch, or 8 per cent. greater; and consequently, by this rule, it would have appeared to be 8 per cent. less; and (12·56 × ·66 =) 9·28 ℔. would represent the effective pressure of the Boulton and Watt Engine: the *ascertained* effective pressure was 9·23, or very nearly the same.

The *mean* pressure of steam is not however usually *ascertained*, and the pressure in the *boiler* is taken as the pressure of steam in the *cylinder*. In this case it was 17·7 ℔. per square inch, and (17·7 × ·66 =) 11·68 ℔. would therefore have represented the effective pressure, which would have made it appear 26 per cent. greater than it really was.

In fact, the effect produced by *every* engine must vary, and therefore any general rule can only give approximate results. The actual result, if required, must be obtained by trial.

As regards the term 'duty,' I understand it to mean the useful effect, or actual weight of water raised by a given weight of coals, the same weight of coals also generating a sufficient quantity of steam to work the engine and overcome the friction of the pit or pump-work. In Cornwall the given weight of coals is supposed to be 94 ℔., because it is stated to be the average weight of a bushel. The weight of an imperial bushel is however fixed at 84 ℔., and as coals are now sold by weight, and not by measure, I have in my Tables thought it best to take the duty done by *one cwt.*, or 112 ℔. weight of coals, instead of a bushel, the weight of which must necessarily vary as the specific gravity of the coal varies.

Upon reference to the Table No. VII., line F, column 36, it will be seen that the duty done by the Cornish Engine when the best Welsh coals were used was equal to 108,198,102 ℔. of water lifted 1 foot high by the consumption of 112 ℔. of coals, or (112 : 108,198,102 : : 94 :) 90,809,121 ℔. by the consumption of 94 ℔. of coals.

The duty is calculated thus:

Data.

1 ℔. of the best Welsh coals will evaporate	9·493 ℔. of water.
The water used per stroke when the engine is working under the circumstances detailed in line F, Table VII., equal to	5·47 ℔.
Area of plunger-pole or pump	9·168 square feet.
Height to which water is lifted	108 feet.
Stroke of pump	9 feet.
Weight of a cubic foot of water	62·5 ℔.

Calculation.

$\overset{\text{sq. ft.}}{9\cdot168} \times \overset{\text{stroke.}}{9 \text{ feet}} = 82\cdot512$ cubic feet per stroke.

$82\cdot512 \times 62\cdot5 = 5157$ ℔. per stroke.

$5157 \times 108 = 556956$ ℔. lifted 1 foot high per stroke.

$\overset{\text{℔. water per stroke.}}{5\cdot47} : \overset{\text{℔. lifted 1 foot.}}{556956} :: \overset{\text{℔.}}{9\cdot493} : \overset{\text{℔.}}{966594}$ lifted 1 foot high per ℔. of coals.

$966594 \times 112 = 108,258,528.$ Duty per cwt.

$966594 \times 94 = 90,859,836.$ Duty per 94 ℔. or Cornish bushel.[1]

It is very certain, if the duty is thus calculated, that the Cornish Engine experimented upon *ought* to have done more duty than any engine in use for mining purposes, because the friction is less, or, in other words, there is less machinery to move to lift the same quantity of water; there are, however, several reasons why the reports of the engines in Cornwall may *represent* a *greater* duty.

1st. The *actual delivery* of water is taken in *my* calculations of duty; and by the use of Harvey and West's valves, when in good order, it is practically demonstrable that the whole quantity of the water, equivalent to the area of the plunger-pole multiplied by the length of the stroke, is delivered *without* loss; but when the valves of the ordinary construction are used, the loss through which is known, and has been proved, to amount to at least $\frac{1}{10}$th of this quantity, no allowance has been made for the loss in estimating the amount of duty done by the Cornish Engines;—the *reported* will therefore, of course, exceed the *real* amount of duty; for instance, it is reported by Messrs. Thomas Lean and Brother that the average duty performed by Taylor's Engine, (diameter of cylinder 85 inches, working at 72¼ horses' power,) from July 1 to August 4, 1841, was equal to 101,595,300 ℔. lifted one foot high by the consumption of a bushel of coals, *assumed* to weigh 94 ℔. Now, deducting $\frac{1}{10}$th from the reported duty, would make the duty

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[1] These vary slightly from those given in the Tables, probably from the same number of decimals not being calculated.

(as calculated in my Tables) equal to 91,435,770 ℔., which is not ¾ per cent. above the duty performed by my engine.

2nd. It is not stated at what part of the stroke the steam is cut off in this engine, but as the piston was of greater diameter, the stroke longer, and the effective pressure per square inch *less*, than in the engine experimented upon by me, it is probable, if not certain, that the steam was cut off sooner, and that consequently expansion was carried to a greater extent; and if so, as a matter of course the duty ought to be greater, in proof of which, by referring to Table VII., and comparing lines B and F, column 36, it will appear that the duty done by the engine, when the steam was allowed to expand only 0·397 of the whole stroke, was equal to 78,535,512 ℔. per cwt., or 65,913,733 ℔. per 94 ℔. of coals; but the *same* engine lifting the *same* load of water, and using the *same* coals, when the steam was allowed to expand 0·687 of the whole stroke, did a duty equal to 108,198,102 ℔. per cwt., or 90,809,121 ℔. per 94 ℔. of coals. Thus, by working *more expansively*, cæteris paribus, the duty was increased 37 per cent.

From the particulars of the work done by this engine (Taylor's) accompanying the published Report, it is evident that it has *more* machinery to work than the one experimented upon by me; and, therefore, unless it worked *more expansively*, or the coals used were of a superior quality, it could not have done the same duty, because it must be borne in mind constantly that be the number of pumps ever so numerous, the distance of one pump from another ever so great, (rendering a system of horizontal rods and levers necessary to work it,) still the Cornish '*duty*' *includes* the friction arising therefrom, be it more or less, and therefore the duty reported is not *necessarily* a criterion of the goodness of the engine.

3rd. The quality of the coals is not stated in these Reports, and it is shown in Table No. II. that the *Welsh* coals vary in quality in the proportion of 7·155 : 9·493, or 32 per cent.

4th. The coals are *measured*, and not weighed, and as the average weight is *assumed* in all cases, whatever the variation may be in the weight of coals, of which 94 ℔. is the average bushel, to that extent there may be an error in the calculation of the work really performed.

From the foregoing remarks it will be evident that, although, as in the case of the term 'horse power,' it may not in itself be objectionable, nevertheless an explanation of the data upon which the 'duty' is calculated is necessary before comparisons can be made, with any degree of accuracy, of the superiority of one engine over another.

'Duty,' however, involves the consideration both of boiler and engine, as superiority of duty may arise from either or both being more perfect; and it is certainly more satisfactory to follow the example of the great Watt, and make them subjects of separate consideration.

TABLE No. I.

DIMENSIONS OF BOILERS.

CYLINDRICAL.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
									Grate.				Surface over fire.			
No.	Length of boiler.	Diameter of boiler.	Diameter of fire tube.	Length of tube.	Diameter of internal tube.	Heated surface.	Water contents.	Steam space.	Length.	Width.	Whole surface.	Air spaces.	Length.	Width.	Area.	Length of flues.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	sq. ft.	cube ft.	cube ft.	ft. in.	ft. in.	sq. ft.	sq. ft.	ft. in.	ft. in.	sq. ft.	feet.
1	27 11¼	6 5⅝	3 10	23 0	1 10	802	442	142	5 2½	3 9	19·50	4·21	5 2½	6 9	35·10	83·76
									5 0	3 9	18·75	4·02	5 0	6 9	33·75	
									4 6	3 9	16·87	3·56	4 6	6 9	30·37	
2	27 10	6 6	3 10	22 10¾	1 10	799	461	131	5 2½	3 9	19·50	4·21	5 2½	6 6	33·80	83·52
									5 0	3 9	18·75	4·02	5 0	6 6	32·50	
									4 6	3 9	16·87	3·56	4 6	6 6	29·25	
3	27 10½	6 6	3 10¼	22 11¼	1 10	803	444	144	5 1½	3 9	19·20	4·14	5 1½	6 6	33·28	83·82
									5 0	3 9	18·75	4·02	5 0	6 6	32·50	
									4 6	3 9	16·87	3·56	4 6	6 6	29·25	
4	27 1½	6 5¾	4 0	22 2¼	1 10	788	400	110	5 2½	4 0	20·80	4·39	5 2½	6 9	35·10	81·37
									5 0	4 0	20·00	4·20	5 0	6 9	33·75	
									4 6	4 0	18·00	3·72	4 6	6 9	30·37	
1, 2, 3, 4	together equal to					3192	1747	527								
1, 2, 3						2404	1347	417								
1, 2, 4						2389	1303	383								
1, 3, 4						2393	1286	396								
1, 3						1605	886	286								
						WAGGON-HEAD.										
	24 2	5 11	ft. in. ft. in. 3 0×2 6	23 9		588	457	347	7 8½	4 10	37·26	3·73	7 8½	5 3	40·42	78·0

NOTES.

Columns 8 and 9. The contents were found by weighing water into the boilers up to the usual water level, and again to the top of the manhole, and dividing by 62·5 ℔.

Column 17; where the flame or heated air divides into *two* flues, only *one* is taken in calculating the whole length.

In the cylindrical boilers the grate is in the fire tube, and the flame or heated air passes to the farthest end, then, dividing, returns along both sides to the front end of the boiler, and, descending, unites again and passes under the boiler to back end thereof. The boiler plates are half an inch thick. The fires were worked by hand.

In the waggon-head boiler the grate is placed under the bottom, and the flame or heated air, passing to the back end, ascends into the internal tube or flue, and, passing to the front, divides, and, traversing both sides of the boiler, unites at the back end. Thickness of boiler plates at bottom ⅜th inch, continuing 2 feet up the sides; remainder of the sides $\frac{5}{16}$th inch; top plates ¼ inch; internal tube ⅜th inch. The fire was supplied by Stanley's fire-feeder.

During the experiments with the cylindrical boilers, sometimes Nos. 1, 2, and 3 were used; at others, Nos. 1, 2, 4, or 2, 3, and 4, &c.: the aggregate heated surfaces, water contents, and steam-spaces are accordingly given in the Table. The length of the grates was also varied, as shown in the Table, which affected the surface over the fire, or radiant heat surface.

TABLE No. II.

THE EVAPORATIVE POWER OF VARIOUS COALS.

The Newcastle Coals were purchased by Contract, the other Coals were purchased without Tenders being offered, and the Merchant's price was given; the only order issued was to have the *best* of the sort for the purpose of trial.

Description of Coals.	Quantity of Coals experimented upon.	Water evaporated per lb. of Coals.
WELSH.		
	lb.	lb.
Pentre, from the heap	98420	7·514
Do. screened, large used	5796	8·709
Eaglebush, from the heap	30576	7·155
Do. screened, large used	6048	8·562
Do. do. small used	6384	7·606
Pentre and Eaglebush, ½ and ½, from heap . .	22260	7·960
Llangynneck, large coals	11200	7·637
Graigola, do.	11340	7·499
Llanelly, do.	9612	7·436
Oakwood Bituminous	31864	7·963
Merthyr, large coals	29652	9·493
Anthracite . . . . , ...	13832	9·014
mean of the foregoing		8·045
NEWCASTLE.		
Newcastle, Bradley, large	316344	7·980
Do. Do. screened	5880	8·443
Do. Adair, large	65352	7·135
Do. Wallridge, large	121464	7·076
mean of the foregoing		7·658
NEWCASTLE AND WELSH.		
Bradley Main, ½ Eaglebush, ½ . . .	44688	8·252
Do. screened, large Do. screened, large . .	6468	8·034
Do. Breeze Do. do. do. . . .	8064	8·063
Do. large, ⅔ Do. Breeze, ⅓ . . .	6636	7·654
Wallridge, small, ½ Pentre, large, ½ . . .	12180	7·323
mean of the foregoing		7·865
NEWCASTLE.		
Small Newcastle	379176	7·678
Do.	161588	8·524
Do.	95060	8·137
Do.	402052	7·958
mean of the foregoing		8·074
VARIOUS SORTS.		
Blythe Main, Northumberland	25898	6·600
Staveley Main, Derbyshire	16604	6·772
Do. and small Newcastle	27580	7·710
Coke, from British Gas Company	3248	7·908
Do. ⅔ Do. Newcastle, small, ⅓	10892	7·897
Do. ½ Do. Do. ½	7728	7·557

TABLE No. III.

SHOWING THE EVAPORATIVE POWER OF THREE SORTS OF COALS, IF THE WHOLE QUANTITY HAD BEEN COMBUSTIBLE.

	Whole quantity of Coals.	Clinkers, &c.	Combustible matter.	Ratios. Columns 1 and 2.	℔. of water evaporated per ℔. of combustible matter.
	℔.	℔.	℔.		
Average small Newcastle .	74760	4440	70320	100 to 5·94	8·553
Blythe Main . . .	13636	1228	12408	100 to 9·0	7·194
Anthracite . . .	11895	1072	10823	100 to 9·0	9·825

TABLE No. IV.

SHOWING THE COMMERCIAL VALUE OF THE COALS.

The price of small Newcastle Coals evaporating 7·68 ℔. of water per ℔. of coals was, in 1840, 14*s*. 6*d*. per ton in the Pool; this price is taken as a standard, and the value given is according to the evaporative power of the different varieties.

	Description of Coals.	Water evaporated ℘ ℔. of Coals.	Value ℘ ton in the Pool.	
			s.	*d*.
1	The best Welsh	9·493	17	11
2	Anthracite	9·014	17	0
3	The best small Newcastle	8·524	16	1
4	Average small Newcastle	8·074	15	2¾
5	Average Welsh	8·045	15	2¼
6	Coke from Gas-works	7·908	14	11
7	Coke and Newcastle small, ½ and ½ . .	7·897	14	10¾
8	Welsh and Newcastle, mixed ½ and ½ .	7·865	14	10
9	Derbyshire and small Newcastle, ½ and ½	7·710	14	6½
10	Average large Newcastle	7·658	14	5½
11	Derbyshire	6·772	12	9¼
12	Blythe Main, Northumberland	6·600	12	5½

1	4	
Referen to expe riments	ed sur- e per e foot orated.	
	. ft.	
1	1·09	Cylindrical boilers covered with ashes. See dimensions, Table No. I.
2	6·77	
3	8·20	
4	6·07	
5	5·66	
6	5·83	
7	6·30	
8	7·00	
9	6·21	
10	5·26	
11	4·76	
12	5·27	
13	8·37	
14	9·03	
15	9·03	
16	5·60	
17	1·83	
18	3·82	
19	0·58	
20	1·00	
21	0·00	
22	1·75	
23	8·45	
24	5·46	
25	6·47	
26	5·00	
27	9·62	Waggon-head boiler; see dimensions, Table No. I. Boiler *exposed;* engine working in day-time only.
28	9·50	Do. *clothed* with 3 coats of hop-sacking do. do.
29	9·62	Do. do. 5 coats do. do. do.
30	9·90	Do. do. 5 coats do. do. the 24 hours round.
31	9·67	Do. do. 5 coats do. do. in day-time only.
32	9·68	Do. do. 1 coat of felt do. do.
33	0·42	Do. do. 2 coats of felt do. do.
34	1·83	Do. do. 3 coats of felt do. do.
35	0·84	Do. do. 3 coats, and top of flues 1 coat do. do.
36	0·78	Do. do. 4 coats, and top of flues 2 coats do. do.

ows the ℔. of water that would have been evaporated per ℔. of coals if it *had not* been so heated in t

TABLE VI.

SHOWING THE EVAPORATION OF WATER AT DIFFERENT TEMPERATURES.

1	2		3	4	5	6	7
Absolute pressure of steam in boilers.	Temperature		Whole quantity of water evaporated.	Coals consumed.	Water evaporated ꝑ ℔. of Coals from temperature of feed.	Water evaporated ꝑ ℔. of Coals from 80°, the latent heat taken as 1037°.	Ratios.
	steam.	feed water.					
℔.			℔.	℔.	℔.	℔.	
53	286·0°	69·2°	609280	75368	8·084	8·158	100·
42	271·4°	73·3°	248640	31208	7·967	8·012	98·21
40	268·4°	69·6°	374080	47202	7·925	8·000	98·06
35	260·3°	70·7°	394240	50699	7·776	7·837	96·06
30	251·2°	70·4°	380800	47316	8·048	8·114	99·46
						Mean	98·358

Column 6 is calculated thus: $\overset{\text{latent heat.}}{1037^\circ} + 212^\circ - 69{\cdot}2^\circ = 1179{\cdot}8^\circ$.

$$\frac{1179{\cdot}8^\circ \times 8{\cdot}084\,\text{℔.}}{1037^\circ + 212^\circ - 80^\circ} = 8{\cdot}158\,\text{℔.}$$

I have thought it advisable to record the facts given in the above Table in support of Watt's doctrine, that "the sum of the sensible and latent heats is a constant quantity." See vol. ii. p. 7, Robison's Mechanical Philosophy.

NGINES.

28	29	30	31	32	33	34	35	36	37	38	39	
DUTIES.												
am power.		Mean resistance.		Load lifted.		Useful effect with Newcastle small coals.		Useful effect with the best Welsh, tried at Old Ford.	Useful effect with coals of the quality described by Messrs. Lean and Brother.	Useful effect with Anthracite.	Useful effect with Derbyshire coals.	
ted 1 ft. high consumption 2 lb. of coals.	Ratios.	lb. lifted 1 foot high per 112 lb. of coals.	Ratios.	lb. lifted 1 foot high per 112 lb. of coals.	Ratios.	lb. lifted 1 foot high per 112 lb. of coals.	Ratios.	lb. lifted 1 foot high per 112 lb. of coals.	lb. lifted 1 foot high per 112 lb. of coals.	lb. lifted 1 foot high per 112 lb. of coals.	lb. lifted 1 foot high per 112 lb. of coals.	
,516,123	100	50,590,318	100	46.328.816	100	43,357,544	100	48,290,112	47,159,164	45,848,139	34.444.331	A
tios 100		91		83·4		78						
,166,560	149·8	82,276,398	162·6	75,345,852	162·6	70,513,544	162·6	78,535,512	76,682,951	74,551,164	56,008,053	B
tios 100		98·9		90·6		84·7						
.310.300	180·6	95.936.088	189·5	87.854.919	189·6	82.220.341	189·6	91.574.133	89.429.479	86.943.339	65.317.922	C

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